Distributed e-Health System with Smart Self-care Units

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Abstract

In order to assure remote monitoring of patients with chronic diseases and also to improve the responsiveness and quality of medical services a distributed eHealth system was designed. A key element of this system is the Smart Self-Care Unit (SSCU) that allows remote acquisition of medical data from patients treated or monitored at home. This unit is composed of a set of smart medical sensors and devices connected through a wireless network. The system assures mobility for the patients under observation and seamless transfer of medical data to the healthcare centers (hospitals, clinics, general practitioners, etc). The patients can interact remotely with medical personnel and may have access to medical services through a distributed, multiserver-based application. A number of autonomous medical applications (servers) deployed in every medical center cooperate in order to offer an integrated healthcare system. Medical information concerning patients enrolled in this system is exchanged between medical entities and self-care units. As part of this system a portal application offers a set of useful medical services such as: information about doctors, medical units and their services, secure storage of personal medical records, discussion forum for patients and doctors or statistical processing of recorded medical data.

1. Introduction

One of the main objective of the "i2010" EU policy framework (towards an „Information society") is the extensive use of IT&C technologies in healthcare systems in order to improve the quality of medical services, increase the system's responsiveness and reduce costs[1]. This IT&C approach will impose fundamental changes [1] in the way healthcare is delivered and medical knowledge is managed and transformed into clinical practices. Ontology-based health-record databases allow flexible representation of complex relations between symptoms, diseases, medication and treatment outcomes [2, 17, 18, 19, 20, 21, 14].

Recently a significant number of national and international eHealth projects were initiated. Some of them strive to find a common platform for medical data interchange, through medical communication protocols (e.g. HL7 [7]), medical services or portals. In the same idea of interoperability, other projects are concerned with classification and unique coding of medical concepts, terms, diseases, drugs and even medical procedures [3,4,5,6]. Medical data-mining, reasoning, statistical processing and other artificial intelligence techniques are used as support for improved medical diagnosis and treatment.

A modern approach of medical service requires orientation to the healthcare consumer, the patient, who must receive medical attention and treatment anytime and anywhere. Nowadays, developments in information technologies and communications (e.g. miniature portable devices [9, 10], sensor networks [11], SOA and web services[12], etc.) offer new opportunities in the implementation of high quality healthcare systems.

A major request imposed for these systems is the integration and interoperability of the different medical applications and services [12], regardless of their regional distribution, ownership or specific medical domains. Patients should access medical services in a uniform and transparent way regardless of their physical location in real or near real-time.

This patient centric approach can be achieved with the intensive use of new classes of portable sensors and medical devices [15, 16, 30] structured in a Smart Self-care unit. This unit allows remote and continuous monitoring of patients in medical facilities (clinics, hospitals) as well as in their homes. There area number

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of initiatives in the field of tele-medicine using smart sensor networks; CodeBlue[31] for instance is an open source project that develops a "scalable software infrastructure for wireless medical devices"; ETag[32] and ETag2[33] extend the hardware/software functionalities of regular wireless sensor motes.

In order to represent medical entities, ideas, and events, along with their properties and relations, a medical domain ontology was adopted as a form of knowledge representation of the medical world [14]. This approach assures seamless exchange of medical data between different medical entities, applications and users. In the same time it gives the support for advanced search, data processing and medical reasoning, using high-level abstractions and concepts.

All these ideas concerning a new approach in medical services were integrated in a distributed eHealth system, called CardioNet, dedicated for patients with cardio-vascular diseases. This paper presents the overall view of the proposed and implemented system and some of its significant parts, such as the smart self-care unit and the medical decision support facility. The rest of the paper is organized as follows: chapter 2 presents the main requirements imposed for a distributed heal-care system, chapter 3 introduces the general architecture of the proposed system, chapter 4 describe in detail the smart self-care unit and chapter 5 present the elements of a medical decision support service. The last chapter concludes the presentation and gives some ideas for future work.

2. Distributed eHealth system - general requirements

Nowadays healthcare is becoming more complex and deinstitutionalized and patients receive care from an increasing number of health-service providers and locations. In this context, distributed eHealth systems, including remote self-care parameter monitoring units, are recognized as having the potential to improve the quality of medical services. Applying the new patient-centered concept of bringing medical care from hospitals and clinics to the patient's home also contributes to an improved health-care service system.

In order to achieve the required level of reliability and dependability for distributed healthcare systems, significant research was done [16, 22-30] and must be done in the following directions:

- development of new mobile medical devices with communication capabilities,
- definition of medical data exchange protocols and standards that allow transparent and seamless access to medical records regardless of their physical location
- definition of coherent and consistent distributed database model capable of revealing multiple relations between stored data
- adoption of data-security strategies that guarantees the protection of medical intimacy of patients, but in the same time assures real-time access to medical records in case of emergencies

A key element of a successful distributed eHealth system is interoperability. According to IEEE definition: „In healthcare, interoperability is the ability of different information technology systems and software applications to communicate, to exchange data accurately, effectively, and consistently, and to use the information that has been exchanged" [13]. eHealth interoperability must be assured at three major layers: syntactic interoperability, semantic interoperability and EHR interoperability [13].

Syntactic interoperability has several sub-layers and is assured through: TCP/IP, HTTP(s), SMTP (email), SOAP or ebXML messaging. The message content structure and the data items in the message must be standardized, as proposed by HL7 v3 [7, 8]. These technologies guarantee message delivery, but don't assure that the content of the message is machine-understandable at the receiver.

Semantic interoperability allows for information shared by systems to be understood at the level of formally defined domain concepts [14]. Another important use of semantic interoperability in the healthcare domain is the integration of data from heterogeneous sources.

EHR interoperability assures that the Electronic Healthcare Record (EHR) of a patient is preserved digitally in a generally accepted standard form regardless of the medical application or entity that generated or stores the data. The EHR format must keep relevant information about patients' state during their lifetime, it must guarantee access security and privacy, but in the same time it must serve educational and research purposes. Unfortunately there is no generally accepted standard for EHR, which makes this kind of interoperability difficult to achieve. This is due to the fact that different countries and different medical domains have very different requirements concerning what and how medical data should be preserved.

Taking into consideration all these general requirements, the authors defined the following set of specifications for the CardioNet system, a distributed medical system for cardio-vascular patients' monitoring and treatment:

- the solution must have distributed medical data repositories, with autonomous medical applications, adapted and deployed to different medical entities;
- applications must be able to exchange medical information through standard interfaces and protocols;
- a centralized portal must assure long term medical records' storage and general purpose medical services;
- patients will access medical services (including interaction with their doctors) through the Internet using common browsers on PCs or mobile devices (cell phones or PDAs);
- the system must facilitate remote patients monitoring, with the use of mobile medical devices, body and environment sensors.

3. The architecture of the CardioNet eHealth distributed system

The CardioNet project is an interdisciplinary applicative research project in concordance with the Romanian public health program started by the Ministry of Health. It was designed to comply with national and international standards and trends in cardiology. The distributed system will include:
- a surveillance and medical data acquisition infrastructure;
- a set of medical applications (servers) deployed at different medical entities and institutions;
- a distributed database system (medical data repository) built upon a domain ontology;
- a set of software services necessary for real-time medical data acquisition, classification, storage and access.

Figure 1 presents a general schematic overview of the CardioNET's medical informational system, emphasizing the actors of the system, their roles and interactions.

From an architectural point of view, the CardioNet system has the following main components:
- Host systems, local production systems (with operative databases h-DB):
- General Practitioner systems;
- Analysis Laboratory systems;
- Hospital systems;
- Smart Self Care Units - SSCU (patients' home systems with personal databases, p-DB);
- Portal (regional, national) for medical assistance, and long term data storage.

Host systems are built of database servers, access points and fixed and mobile interconnected medical devices. The CardioNET portal will provide the

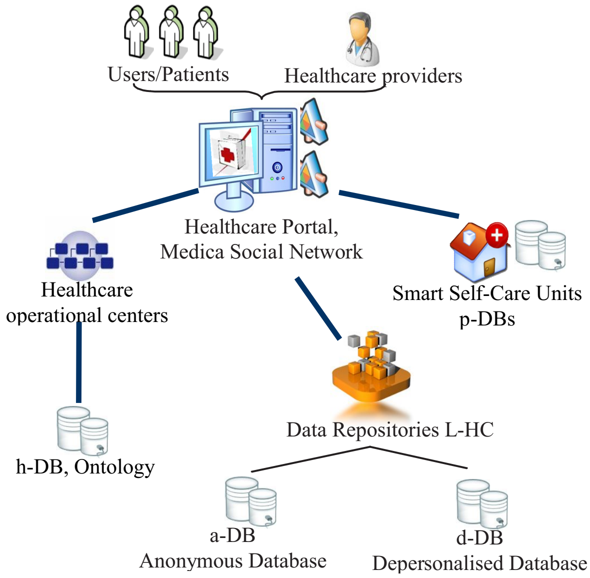

Figure 1 – CardioNet - distributed eHealth system logical overview

architecture required to collect information from the mentioned local systems into centralized repositories (a-DB and d-DB). At the portal level, "patient-centric" medical services will be discovered using specialized registries that among other functions, will allow access to data stored in the previously mentioned repositories.

In order to assure maximum interoperability, the CardioNET portal was designed based on a SOA architecture, allowing heterogeneous systems' integration. Due to its flexibility, CardioNET system offers its partners the possibility to use almost any hardware or software platform. The system's translation functions (adapters) assure interoperability with minimum implications for the interacting systems. The first interoperability test for the portal was made with a medical database of an analysis laboratory, designed and deployed on an Apple-Mac platform using FileMaker.

CardioNET system was designed such that it will work in both directions: as a service producer (provider) and as a service consumer (requester). Using a service oriented architecture based on IT&C standards, CardioNET allows creation of composite applications by orchestrating web services stored in private domain repositories. The GUI level permits dynamic interface creation, using specialized controls and templates, managed in an "event-driven" approach with the help of WPF-XAML technology. The communication between service consumers and service providers is accomplished through a midleware called „Health Service Bus - HSB" [15]. This middleware provides the support for service descovery (using the

UDDI standard), data exchange and access to specialized software services (e.g. medical data processing procedures).

4. The Smart Self-Care Unit - SSCU

The smart self care unit is a set of medical and IT interconnected components used for data acquisition, data aggregation and event-based monitoring. Besides the data acquisition and monitoring functionalities, the SSCU offer the interface for remote medical consults, including multimedia transmission.

The Self-care units, located at the patient's residence or hospital, are connected to the system through the Health Service Bus (HSB). The SSCU is built on top of many types of devices, connected through dedicated wireless networks: body sensors and mobile medical devices, environmental sensors and static medical devices. The "smart" part of the system is a desktop (PC) or a portable computer (PDA) responsible for initiating periodical data acquisition procedures, storing the data and communicating with the other components of the CardioNet system. It also provides the graphical user interface for patients that whish to interact with medical personnel or to access other medical services offered by the system (e.g. social networking, search services, etc.).

The computer communicates with sensors and medical devices through a wireless sensor network, using the 802.15.4 standard (a low-rate wireless personal area network) or through a cable-based local network. The networks are composed of several wireless sensor devices, called motes, consisting of an embedded microcontroller, a low power radio and a

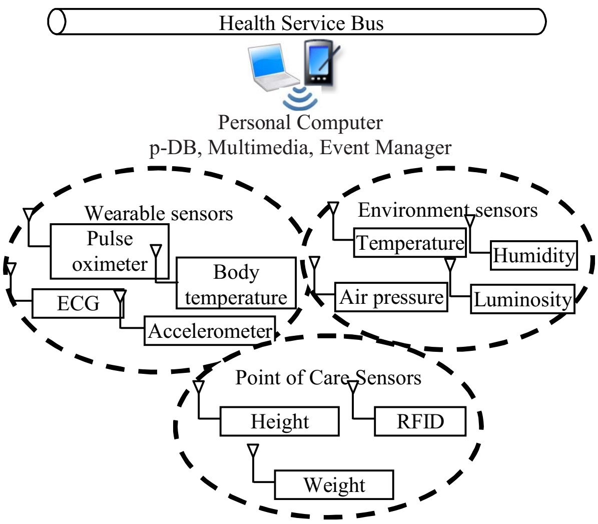

Figure 2. Components of the Smart Self-Care Unit

small amount of local storage memory. The network nodes are running a simplified operating system called TinyOS that facilitate resource management and concurrent execution of tasks.

The use of SSCUs adds important features to the system and assures some local services, such as:

- assures remote and continuous monitoring of patients with chronic diseases;
- reduce health-care costs replacing hospital care with home surveillance and remote nursing;
- improves healthcare responsiveness and increased quality of medical services;
- provides greater mobility and comfort for the monitored patients;
- assures higher efficiency due to event-based remote monitoring;
- provides knowledge-based data aggregation and sensor fusion;
- provides basic tools and utilities for specialists in their clinical trials.

In order to assure these facilities and requirements a SSCU integrates the following components(Figure 2):

- personal computer or PDA;
- medical equipment and sensors with communication capabilities;
- wireless ambient sensor network (as part of an Integrated Ambient System – IAS[34]);
- wireless sensor network for patient's vital sign monitoring;
- wireless sensor network for environment sensors;
- RFID reader/writer for electronic identification of patients and data recording.

The personal computer/PDA has the main role of processing the data received from the various sensors and storing them in the local personal database, p-DB. For instance, if the "point of care" is affiliated to a data repository (portal) then the station will delivery the information to the data repository whenever new data and an Internet connection is available. Other important functions of the personal station are: medical events management, personal-DataBase administration, multimedia instant messaging with the medical professionals.

Given the complexity and various data sources for patient vital sign monitoring we used a set of medical devices from Corescience: the EMI12 development kit – a 12 lead ECG module, the NiBP2010/ChipOx development kit for non invasive blood pressure and pulse oximeter. In order to test the system without the need of patients, a set of sensor simulators were developed; these simulators copy the physical characteristics and technical specification (transmission

Figure 3. Ambient temperature monitoring

rate, sampling rates, data/packet format) of real medical devices.

The next figures present some snapshots of equipments included in the SSCU: Figure 3 presents results obtained from the ambient sensor network, which monitors the temperature from a set of three sensors deployed (in different locations) at the patient's residence. Figure 4 presents the RFID enabled PDA reader and the passive RFID wristband for a patient.

Regardless the location of healthcare services (home, ambulatory) the wireless sensor networks for patient's vital signs monitoring have to meet the same tight constraints and specifications concerning low battery consumption, lightweight wireless node design and versatile use. Given the presented requirements the TinyNode platform [36] was selected as developing tool. This platform offers basic communication facilities and network administration services. But in order to facilitate seamless access to medical parameters a communication middleware was developed.

5. The Virtual device concept and the communication middleware

Various input data sources (sensors, written observations, signatures, symptoms) were aggregated in a virtual device component. The virtual device concept allows higher level software services to treat information in a uniform way regardless their source or physical location. Moreover, the virtual device performs transformation functions converting raw data into structured data (for instance raw ECG measurements will be converted into widely accepted standards such as SCP-ECG). The virtual device concept is present both at the level of TyniNode' middleware and in the application running in the computer.

Figure 4. RFID based patient identification

The hardware infrastructure assures a context aware physical monitoring of patients with event generation possibilities, performing rapid notification of the patient's personal medical specialist. The patient-specialist meetings are be possible using messeging functionalities, where the patient will be able to contact his/her own medical specialist.

The middleware proposed for the wireless nodes is an adapted version of the TinyDB software. Although significant effort was carried out towards medical monitoring and reliable communication, significant gaps remain between existing sensor networks designs and the requirements of medical monitoring applications.

The middleware handles both ambulatory and home care monitoring services. While for home care services one receiver can handle the load of routing information from the whole wireless network, for ambulatory purposes multiple receiver units are required [35]. Our early results show that the 200 kilobytes throughput assured by the IEEE 802.15.4 minus the overhead of routing protocols are enough to handle about 100packets/second, which consequently mean 100kHz sampling period for a regular wireless mote; it is assumed that one network packet is enough for the information generated at a sampling rate of 1kHz. The previous example uses a network with a maximum of two hops, in a home-care scenario, where most of the traffic is generated by constant monitoring of ECG signals. It is known that for regular ambulatory-care the 100kHz sampling rate for the ECG is mandatory.

Packet flow control was solved through prioritization; the user, through the middleware can configure the priority of the different packet types based on their emergency. However in the case of dropped/delayed packets where the delay time would be greater than a given threshold, the result is generated using basic interpolation techniques.

6. Medical decision support

An important goal of the proposed system is to provide support and guidance for medical decision and treatment. In order to fulfill this goal a number of components and methodological approaches were combined.

A main element of this synergic construction is the ontology-based organization of medical data repositories. The first step of this approach was to identify concepts, relations and processing scenarios involved in different medical acts (called later episodes) and map them into a coherent and flexible data-base structure. This process required medical expertise in identifying relevant entities and relations and also a proper IT approach. For instance a single concept like "medication" may have a significant number of aspects and nuances, such as: previous medication, currently using medication, imposed medication, recommended medication, association with other medication, relation with diseases, medical devices and procedures, adverse effects, etc.

Our efforts were focused mainly on the definition of an ontology for cardio-vascular diseases, but many parts may be used and extended for other categories of illnesses. The main concepts around which the ontology is organized are: patient characteristics, signs&symptoms, syndroms&effects, diagnoses (with subclasses of blood disease, hart failures and other hart diseases), treatment, medication, medical procedures, medical devices and patients. There is a total of 231 concepts and 2020 instances of concepts included in the ontology.

The flexibility and scalability of the proposed solution is given by the fact that new concepts, sub-concepts and instances may be added to the ontology without chancing the structure of the data-base. A new concept is "just" a record or slot in a table of the data-base. The flexibility is also assured in case of recording facts and medical data about episodes of a patient. A variable, logically unlimited, number of facts and treatment decisions may be added to an episode entity. These facts may be instances of other concepts (e.g. signs and symptoms), values of measured medical parameters (e.g. blood pressure) or strings (not formalized observations). The second element of the medical decision support system is a predefined set of medical plans. A plan is a tree-like procedural scheme that allows a doctor to determine the most probable disease and treatment based on the facts related to an episode of a patient. A plan establishes which are the necessary observations and tests in order to determine a given diagnose. These plans gather in a formalized and precise way clinical experience and procedural rules for different diseases and their treatment. Plans are used by the system in order to guide the doctor in evaluating the patients' state and also help him in taking the proper decisions. Figure 5 present an example of such a plan defined for hypertension symptom.

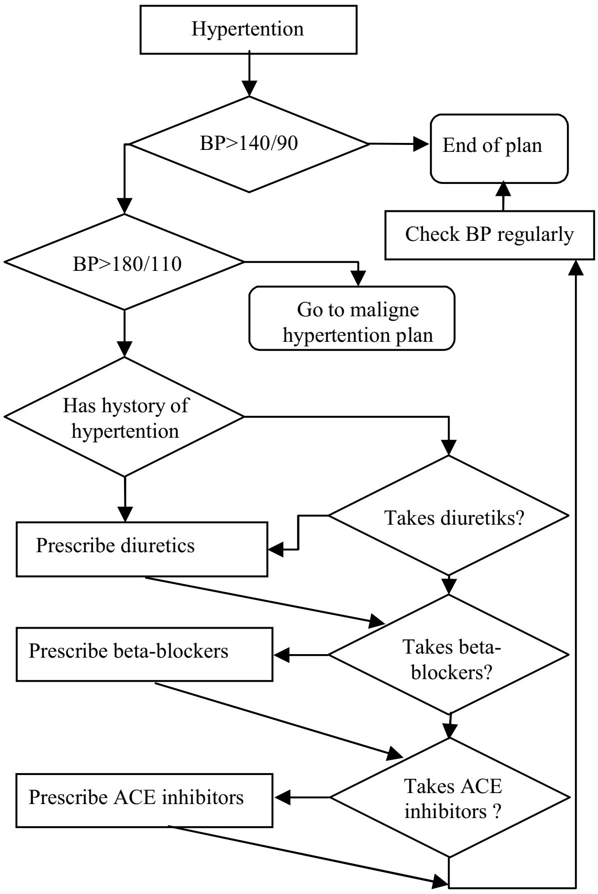

Figure 5. Decision support plan for hypertention (partial plan)

In the first stages of a patient's assessment a number of plans are activated; as medical facts are gathered only the plans with higher confidence (probability) level are preserved. Finally the doctor based on probabilistic values will decide on the best treatment procedure.

An important component of this decision process is the self-care unit that allows continuous and real-time monitoring and evaluation of the patient's state. In this way diagnosing and medication prescription is not a "one time" or disrupted process, but a continuous one.

This aspect is very important in the case of patients with chronic diseases like cardio-vascular, diabetes or cancer illnesses where continuous assessment and adaptation of medical treatment is essential for the long term success of the medical act.

Another element of the medical decision support system is the ability offered by the system to make search and statistical evaluations on the stored medical data repository. Depersonalized and anonymous medical data is available for analyses not only for the currant doctor but for the whole community of medical personnel enrolled directly or indirectly in this system; directly, as user of this system or indirectly as a user of another medical application that may ask for statistical data through the standard HL7 protocol. A special component of the system is meant to respond to such requests.

7. Conclusions

Implementing a distributed eHealth system is a complex task that involves: remote data acquisition and monitoring, data logging and information exchange between medical entities, applications and users. The paper presents a model of a Smart self-care unit as the solution for remote monitoring of patients' medical state. Based on a sensor network, the unit collects patient and environment parameters and sends them to a medical entity (e.g. general practitioner, clinic, etc.). The unit also allows remote interaction between patients and medical personnel.

The information gathered is preserved in a specialized database built upon a domain ontology. This approach reviles complex relations between different concepts involved in a medical act (episode). The ontology-based solution also assures the interoperability and transparent exchange of data between different medical applications.

Medical plans associated with the domain-specific ontology offer the support for better medical diagnoses and treatment. These plans guide medical personnel in the process of patient's evaluation, diagnosis and treatment, avoiding mal-practice cases.

The proposed solutions were implemented for monitoring and treating patients with cardio-vascular diseases. This approach reduces significantly the time spent by patients in hospitals, allows continuous monitoring of patients with chronic diseases and facilitates flexible interaction between patient and doctor through the Internet.

As future work, the authors intend to add more elements of intelligence to the system through data-mining procedures, statistical evaluation facilities and alternative decision support services.

8. References

[1] European Information Society: *http://ec.europa.eu/information_society/*, *http://ec.europa.eu/i2010*, *http://www.ehealth-era.org/*, *http://ec.europa.eu/information_society/tl/qualif/health/*

[2] A. L. Rector, W. D. Solomon, W. A. Nowlan, T. W. Rush, "A terminology server for medical language and medical information systems", *Methods of Information in Medicine*, Vol. 34, North Holland, 1995, pp. 147-157.

[3] *International Statistical Classification of Diseases and Health Related Problems (The) ICD-10 Second Edition*, World Health Organization, 2004.

[4] M. Stark, "A look at LOINC - The Established Standard for Lab Data Gains Visibility as Data Exchange Increases", *Journal of American Health Information Management Association*, 2006, 77(7):52, 54-5; 57-8.

[5] U.S. Food and Drug Administration (FDA), The National Drug Code Directory, *http://www.fda.gov/cder/ndc/*, 2008.

[6] K. Spackman, K. Campbell, R. Côté, "SNOMED RT: a reference terminology for health care", *Proc. of the 1997 AMIA Symposium*, Nashville, 1997, pp. 25-29.

[7] Health Level 7 (HL7), *http://www.hl7.org*, 2008.

[8] HL7 Clinical Document Architecture, Release 2.0, *http://hl7.org/library*, 2004.

[9] HealthFrontier Inc., *http://www.healthfrontier.com/Products/*.

[10] Nonin Medical Inc., *http://www.nonin.com/*.

[11] Radianse Inc., *http://www.radianse.com/*.

[12] Dogac A., Cingil I., Laleci G., Kabak Y., "Improving the Functionality of UDDI Registries through Web Service Semantics", *3rd VLDB Workshop on Technologies for Eservices*, Hong Kong, China, 2002.

[13] Harmonisation, interoperability and standards issues, *www.betterbreathing.org/*.

[14] Gh. Sebestyen, G. Saplacan, C. Cenan, M. Rusu, L. Krucz, T. Nicoara, A. Sebestyen, "Ontology-based Remote Medical Service Provisioning for Patients with Cardio-Vascular Diseases", *microCAD International Scientific Conference*, Miskolc, Hungary, 2009, pp.109-117

[15] M. Rusu, L. Krucz, C. Cenan, Gh. Sebestyen, T. Nicoara, N. Todor, G. Saplacan, "Home Health Care Units in telehealth systems", *5th Conference of the Eastern Mediterranean Region of the International Biometric Society (EMR-IBS)*, Istanbul, May 10-14, 2009

[16] Hein A., Nee O., Willemsen D., Scheffold T., Dogac A., Laleci G.B., "SAPHIRE - Intelligent Healthcare Monitoring based on Semantic Interoperability Platform – The Homecare Scenario", *1st European Conference on eHealth (ECEH'06)*, Fribourg, Switzerland, 2006, pp. 191-202.

[17] A. Jovic, M. Prcela, D. Gamberger, "Ontologies in Medical Knowledge Representation", *Proc. of Int. Conf. Information Technology Interfaces*, 2007, pp. 535 – 540.

[18] European Society of Cardiology – Task Force, "Guidelines for diagnosis and treatment of the chronic heart failure", *http://www.escardio.org*, 2005.

[19] D. M. Pisanelli, A. Gangemi, G. Steve, “A Medical ontology library that integrates the UMLS MetathesaurusTM”, Lecture Notes In Computer Science. Vol. 1620, *Proc. of Joint European Conf. on Artificial Intelligence in Medicine and Medical Decision Making*, 1999, pp. 239-248
[20] J.J. Michel, A.F. Cutting-Decelle, "The Process Specification Language,", *International Standards Organization ISO TC184/SC5 Meeting*, Paris, April, 2004.
[21] National Guideline Clearinghouse, http://www.guideline.gov/summary/summary.aspx?ss=15&doc_id=9725&nbr=5208.
[22] EPI-Medics project portal, *http://epi-medics.insa-lyon.fr*
[23] HOME project portal, *http://www.at-home-medic.net*
[24] TOPCARE project portal, *http://www.topcare-network.com*
[25] MOBI-DEV project portal, *http://www.mobi-dev.arakne.it*
[26] TELEMEDICARE project portal, *http://www.telemedicare.net*
[27] SAPHIRE project portal, *http://www.srdc.metu.edu.tr/webpage/projects/saphire/*
[28] Microsoft Healthvault – Health monitoring system, *http://msdn.microsoft.com/en-us/healthvault/*
[29] METeOR – Australia’s national repository for health metadata standards, *http://meteor.aihw.gov.au*
[30]MobiHealth Project- mobile services for applications in healthcare, *http://www.mobihealth.org/*
[31] CodeBlue, *http://www.eecs.harvard.edu/~mdw/proj/codeblue/*
[32] ETag, *http://www.cs.virginia.edu/~ls2ef/wsn/ETag/*
[33] ETag2, *http://www.cs.virginia.edu/~ls2ef/wsn/ETag2/*
[34] W. Labidi, J.F. Susini, P. Paradinas, M. Setton, “XMPP based Event notification Middleware for Real-time and Large Scale Health Care Integrated Ambient systems”, Developing Ambient Intelligence, *Proceedings of the International Conference on Ambient Intelligence Developments*, 2007
[35] V.Shnayder, B. Chen, K. Lorincz, T.R.F. Fulford-Jones, M. Welsh, “Sensor networks for medical care”, *Proceedings of the 3rd international conference on Embedded networked sensor systems*, 2005
[36] TinyOS, http://www.tinyos.net

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